# Revised View of Solar X-Ray Jets

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# Introduction: Solar X-Ray Jets

- Observed since the Yohkoh days (Shibata et al. 1992; also Shimojo et al. 1996, etc.)
- Yohkoh (SXT) saw them mainly in active regions.

- Hinode/XRT found them to be plentiful in polar coronal holes (Cirtain et al. 2007; also Savcheva et al. 2007, etc.)
- In polar coronal holes: size~50,000 km x 8000 km; rate ~60/day (Savcheva et al. 2007).
- Often have a “hot loop” at the jet’s base.

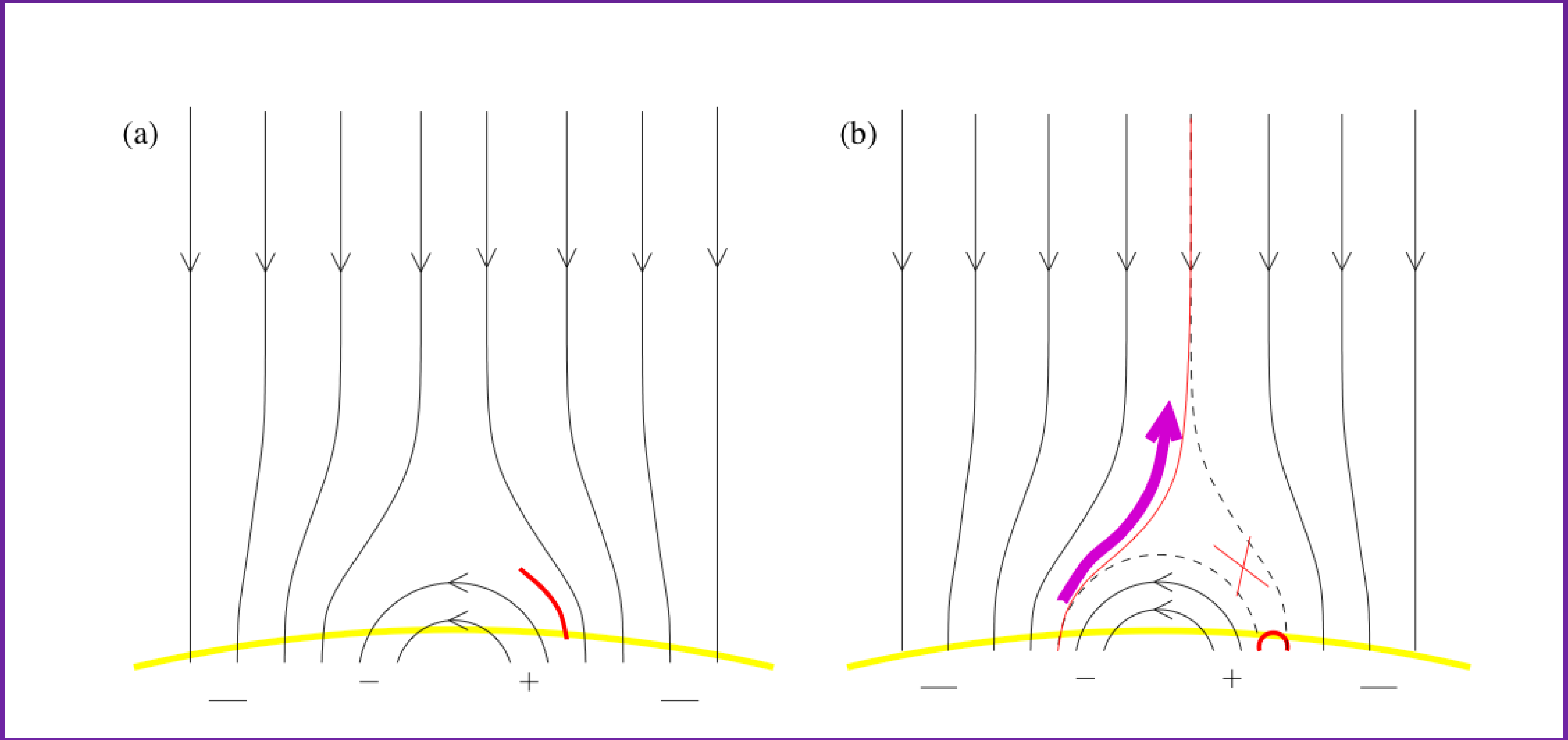
Often-discussed mechanism is based on emerging flux ("emerging-flux model"). (Shibata et al. 1992;  see also Moore et al. 2010.)

Many of the above observations and mechanism ideas were largely deduced from SXRs, and specifically from pre-SDO AIA observations.

Next:  An overview of the emerging flux idea.

Later:  Observations of (X-ray) jets using AIA, and resulting implications for the emerging-flux mechanism.

# Emerging-Flux Model for (X-Ray) Jets




Supported by numerical simulations: Yokoyama & Shibata (1995), Nishizuka et al. (2008), Archontis et al. (2013), Moreno-Insertis et al. (2013), Fang et al. (2014), etc.

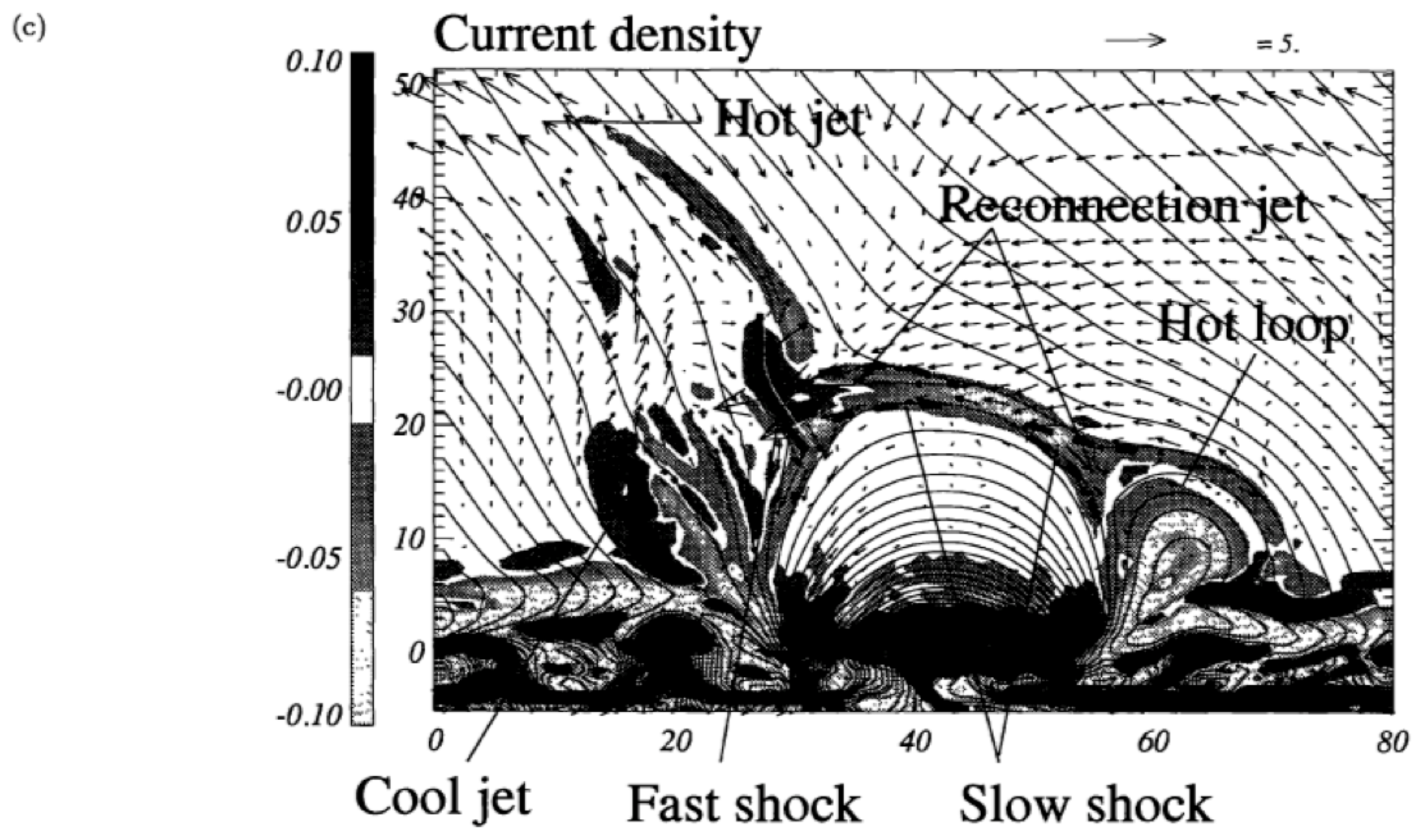



Fig. 9. Simulation results of the typical model (model 7) for the oblique-coronal-field case, $\theta_{\mathrm{cor}} = 3\pi/4$. The figure shows the region near to the central loops (lower half of the computation box), whose range is $0 \le x \le 80$ and $-5 \le z \le 50$. Panels (a) and (b) show the time evolution of the temperature $T$, and the density $\log_{10}\rho$, respectively. Panel (c) shows the current density $J_y$ distribution at $t = 105.0$. The remaining notation is the same as in figure 3. (See Plate 9 for figure 9a.)

(Yokoyama & Shibata 1996, PASJ)

# Standard Jets and Blowout Jets

- X-ray Jets, from the time of Yohkoh: E.g., Shibata et al. (1992); Shimojo et al. (1996); and Hinode, e.g., Cirtain et al. (2007).
- Jet model, later known as “standard jets”:
  - Shibata et al.
  - Yokoyama & Shibata (1995, 1996)
  - Moreno-Insertis et al. (2008)
  - Archontis & Hood (2013)….

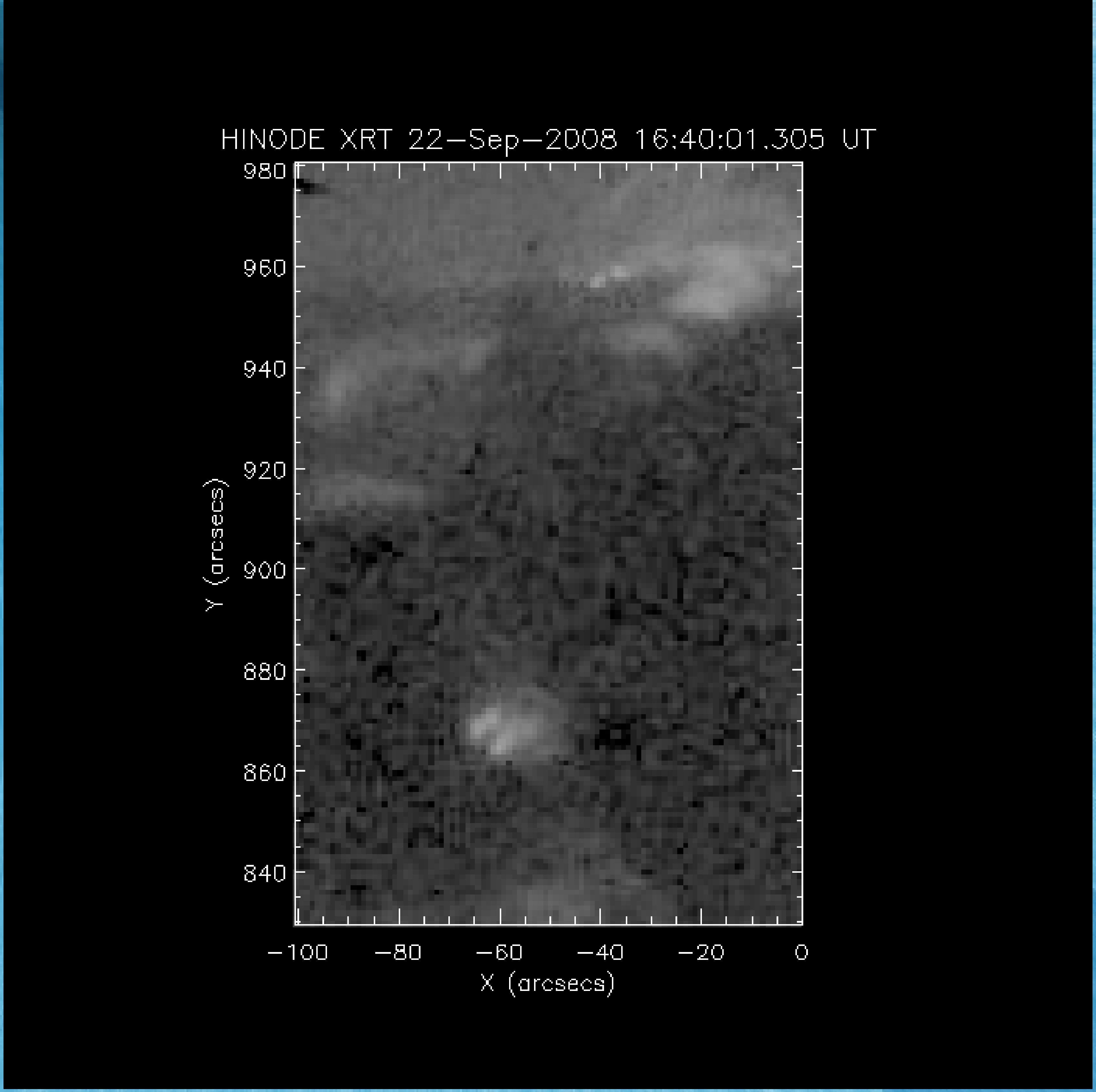
- Dichotomy: Standard and Blowout Jets
  - Moore et al. (2010)
  - Moore et al. (2013)
  - Blowout jets seen by several workers (Liu et al. 2011, Standard to Blowout; Hong et al. 2011,Shen et al. 2012, CMEs with blowout jets; Moreton et al 2012; etc.)

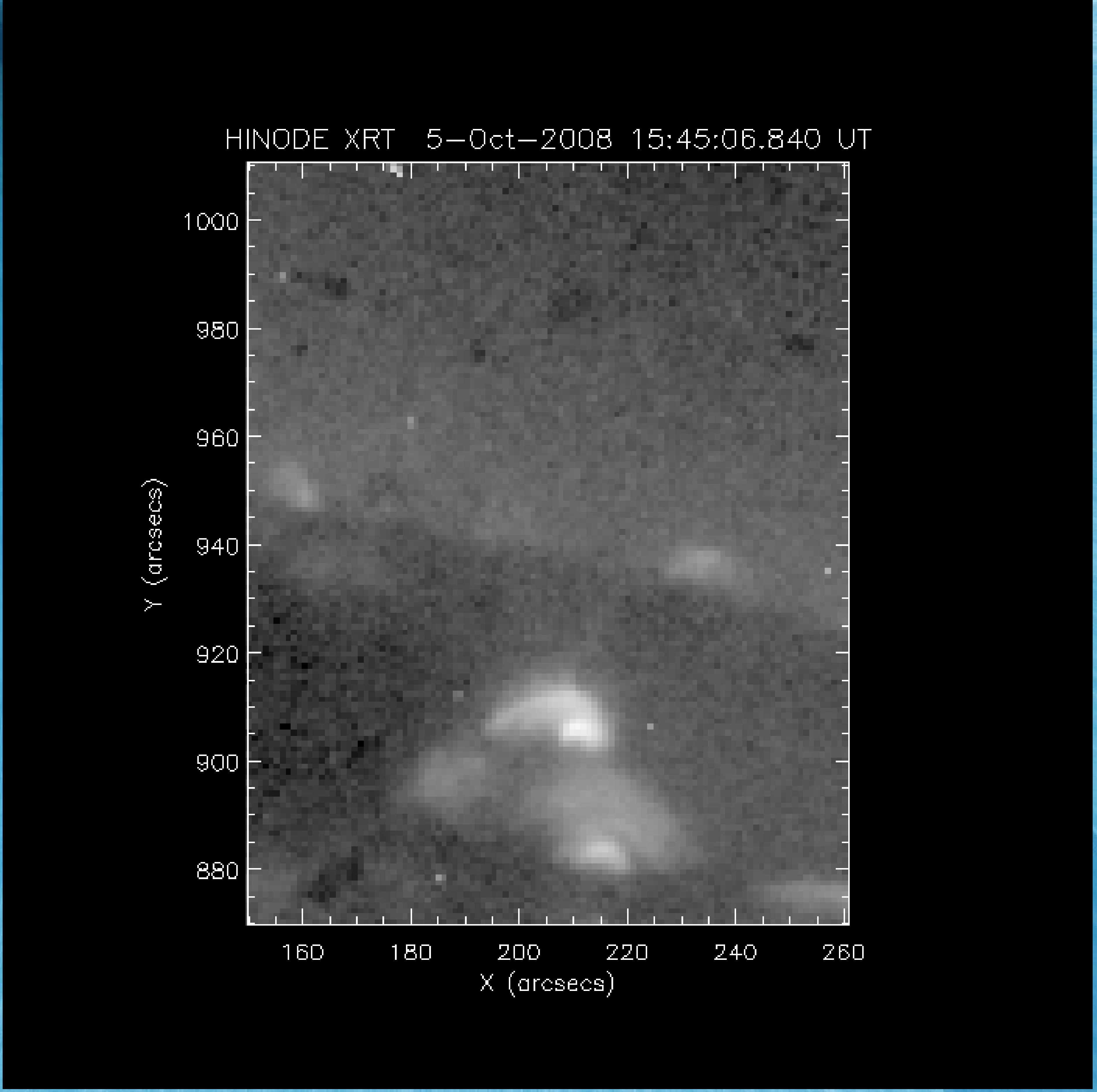
# Standard vs. Blowout

(Moore et al. 2010, 2013)

- Standard:
  - Simple (“single”) spire
  - Little X-ray brightening at base, cf. bright point
  - Little or no emission in cooler lines.
- Blowout:
  - Complex, broad spire
  - Strong X-ray base brightening at base
  - Substantial cool ejective jet

# “Standard Jet” Examples


HINODE XRT 22-Sep-2008 16:40:01.305 UT
Y (arcsecs)
980
960
940
920
900
880
860
840
-100
-80
-60
-40
-20
0
X (arcsecs)

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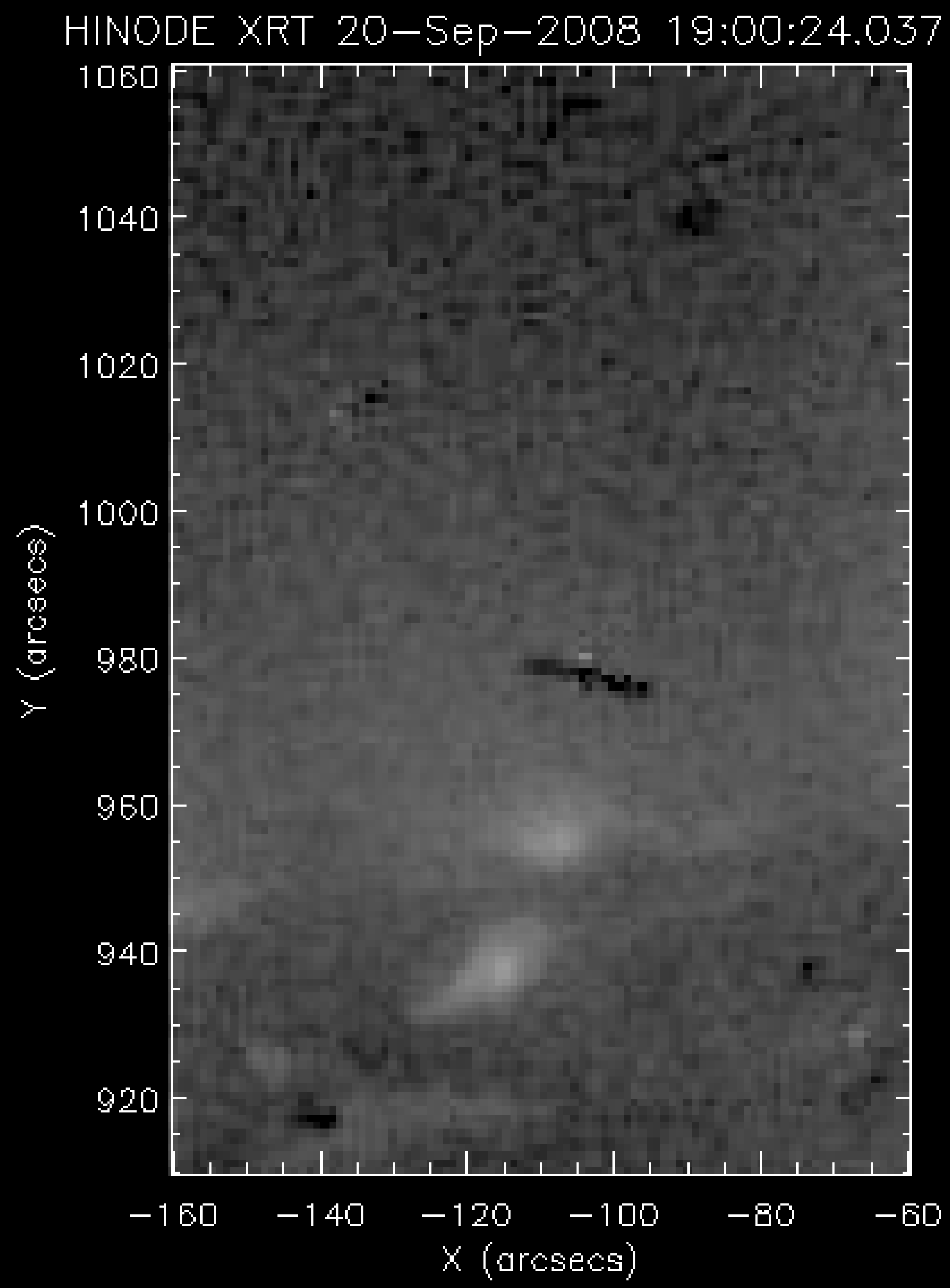
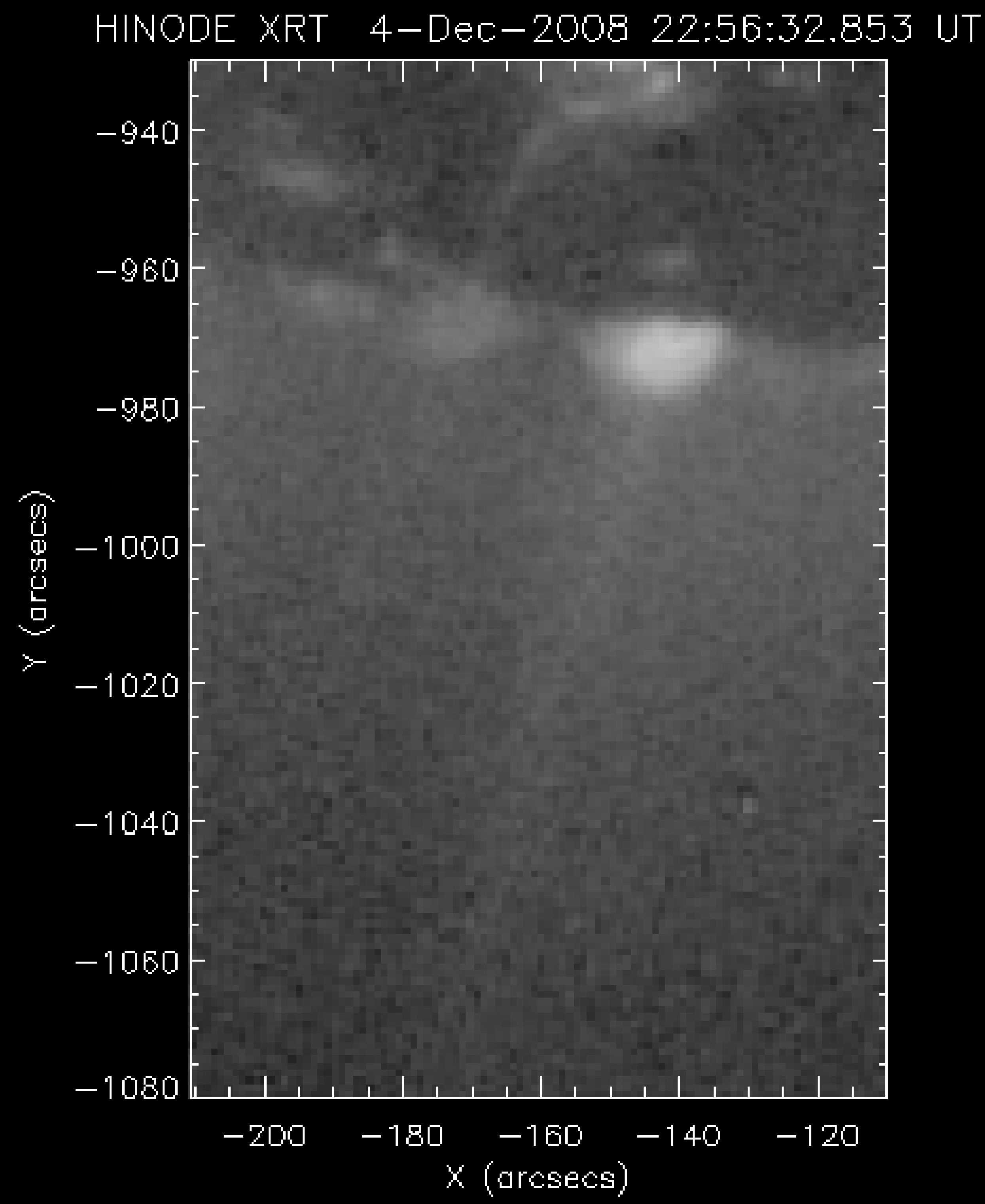
“Blowout Jet” Examples


HINODE XRT 20-Sep-2008 19:00:24.037 UT
1060
1040
1020
1000
980
960
940
920
Y (arcsecs)
−160
−140
−120
−100
−80
−60
X (arcsecs)

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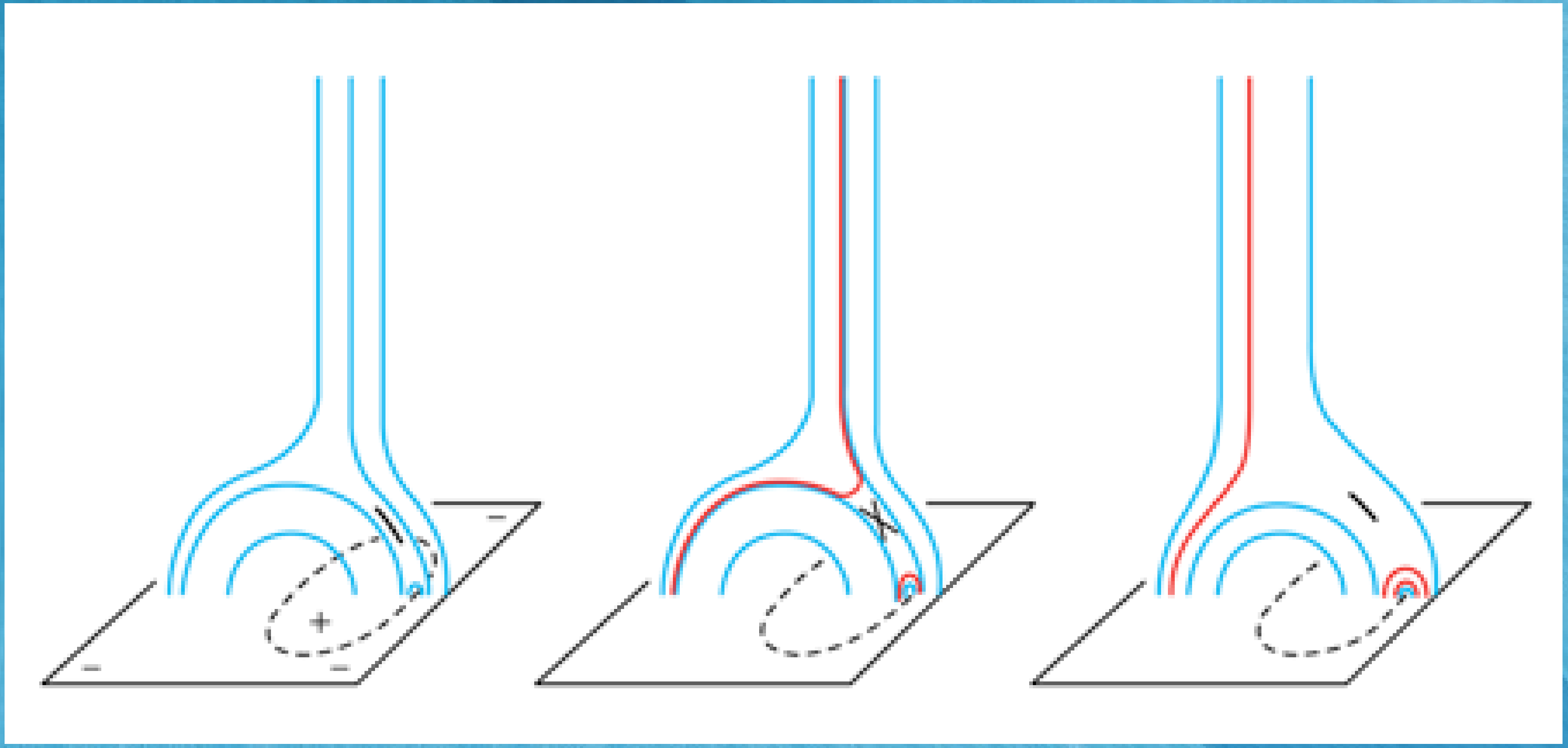
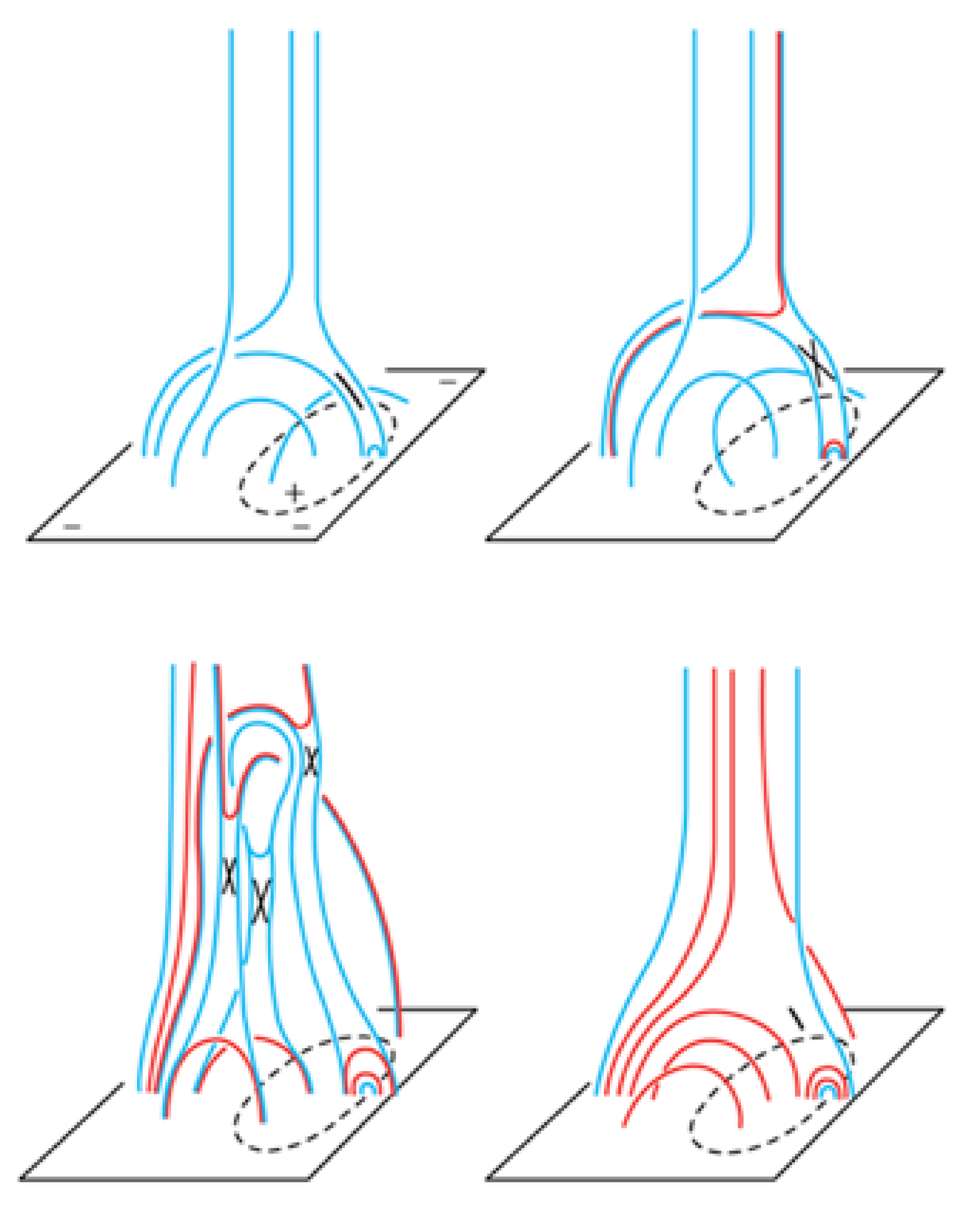


Moore et al. (2010)




Moore et al. (2010)

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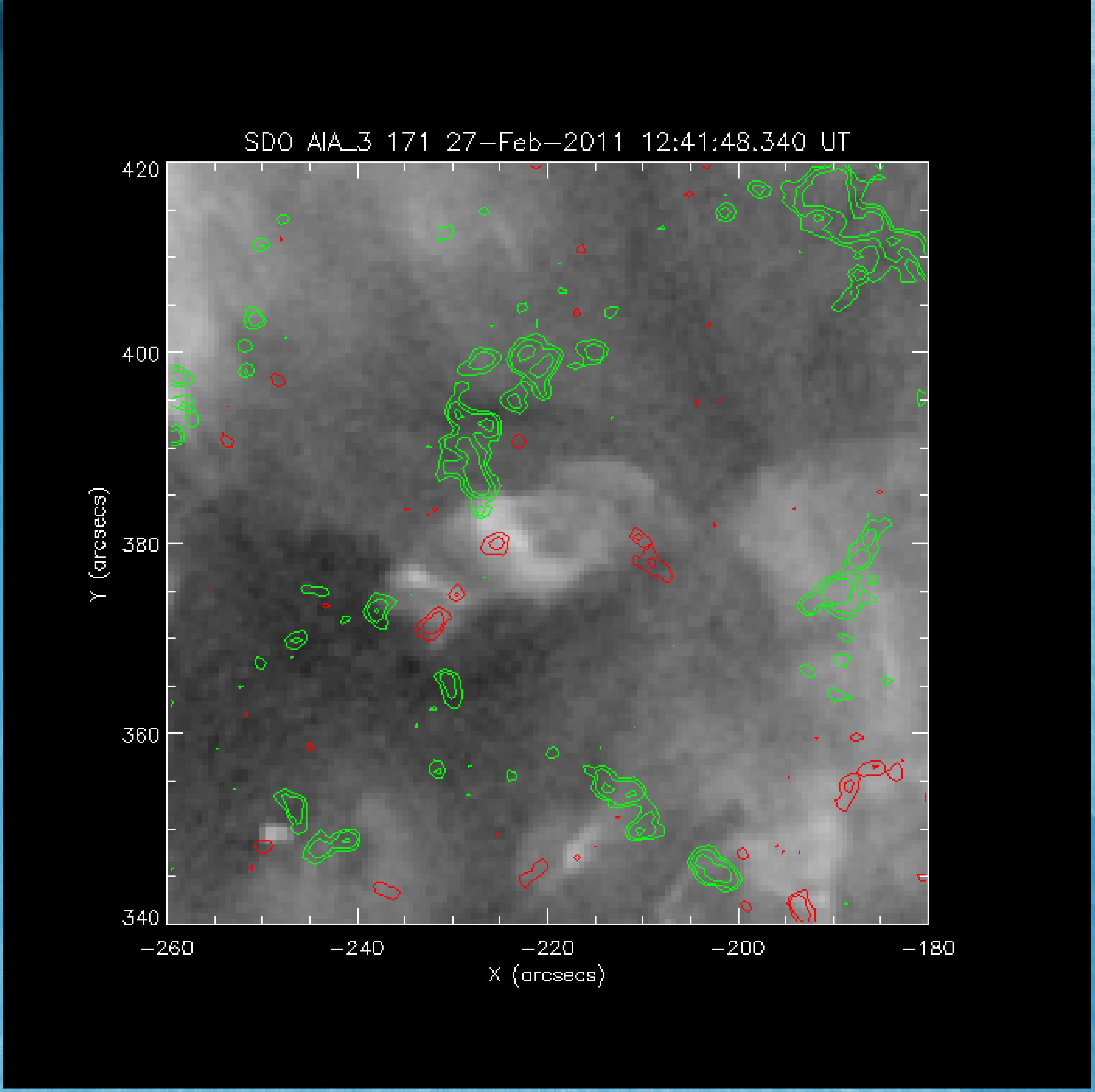
# Jets with AIA (mainly our work)

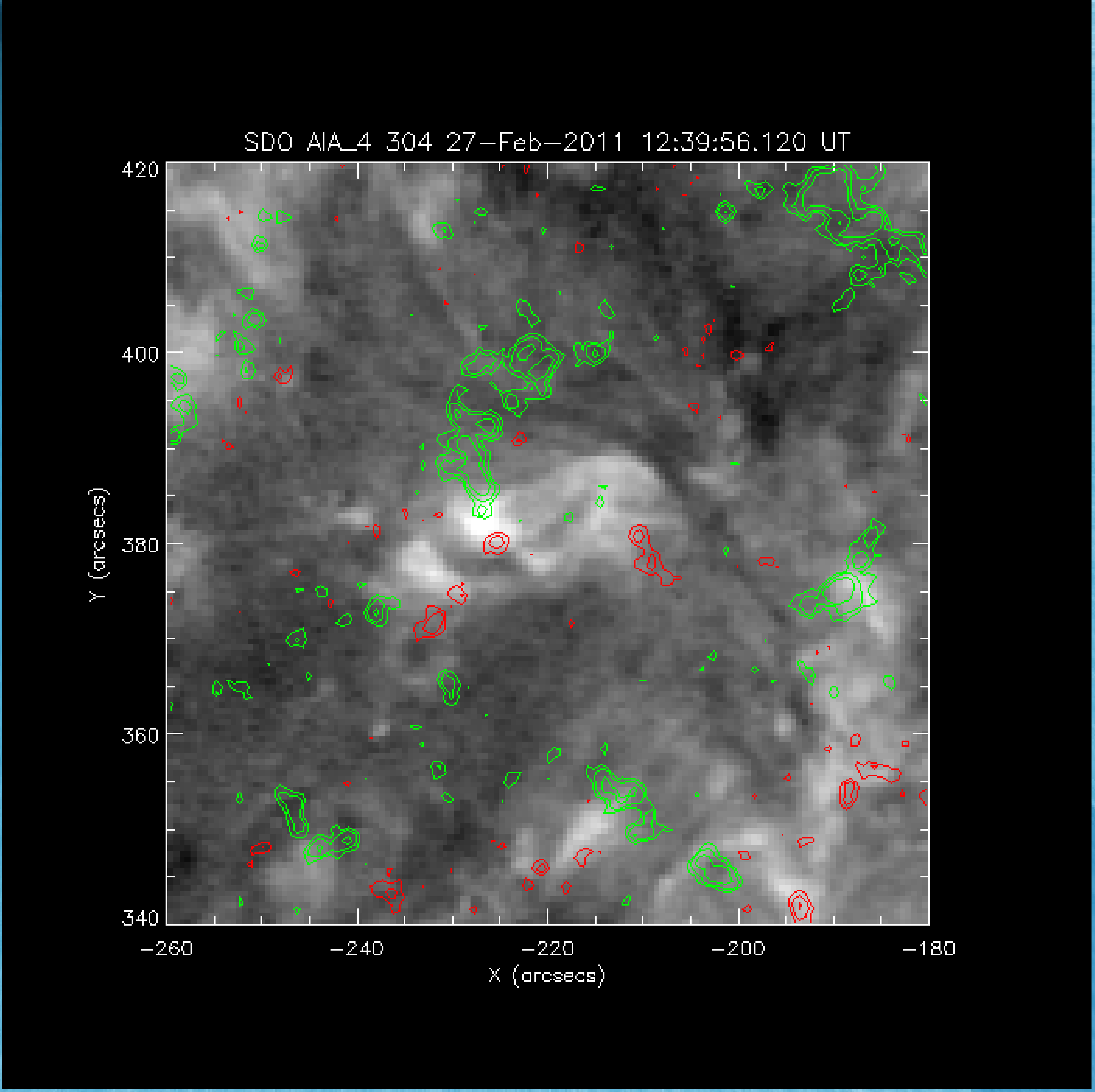
# On-Disk Macrospicule

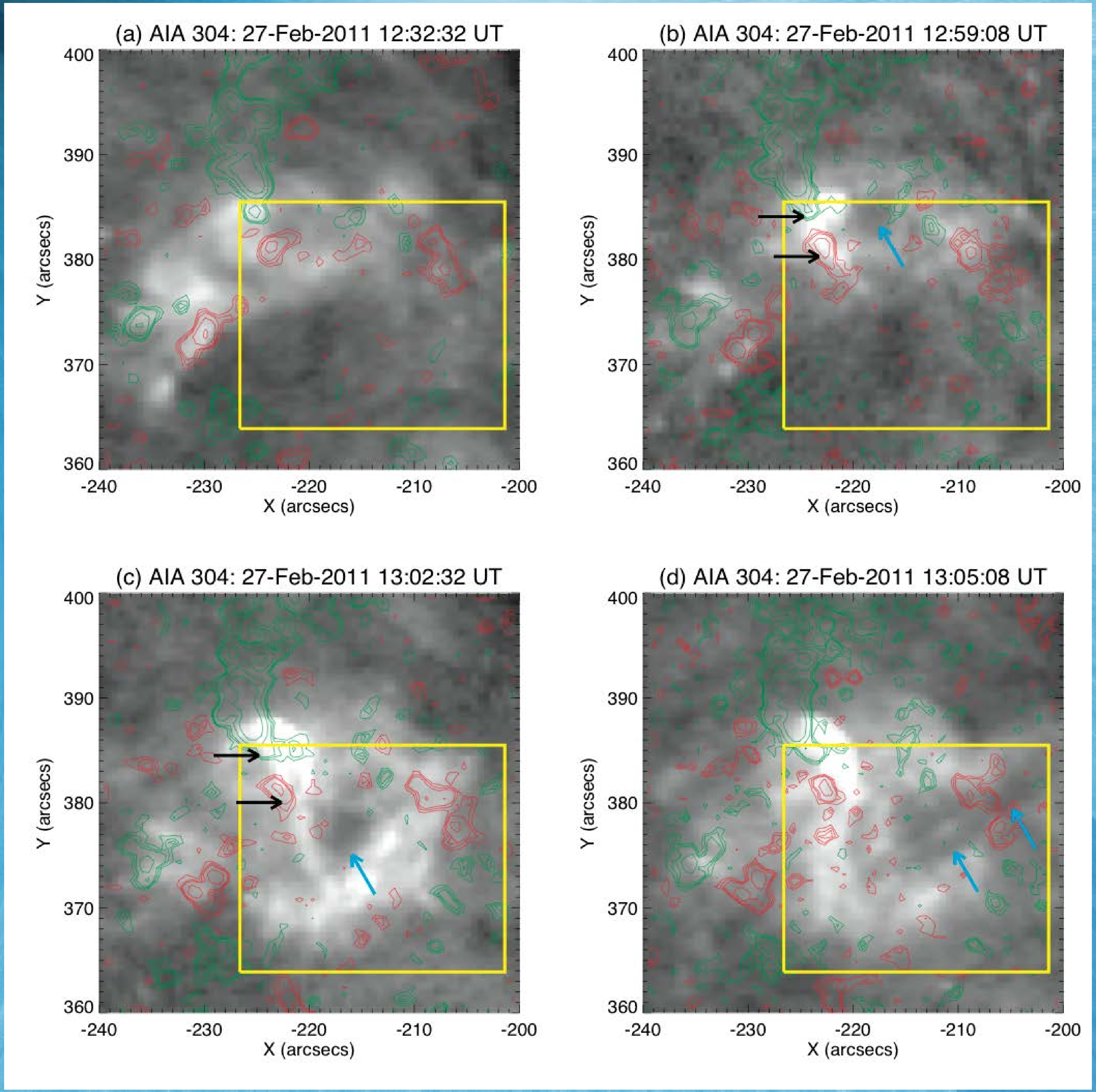
(Mitzi Adams, Sterling, Moore, & Gary 2014)

- AIA and HMI observations.
- In on-disk Coronal Hole.
- No obvious AIA hot-channel jet; therefore might be a “macrospicule,” but not certain (X-rays??)..
- On-disk, so look for Shibata/Moore EFR source for the jet.



SDO AIA_3 171 27-Feb-2011 12:41:48.340 UT
420
400
380
360
340
Y (arcsecs)
-260
-240
-220
-200
-180
X (arcsecs)


SDO AIA_4 304 27-Feb-2011 12:39:56.120 UT
420
400
380
360
340
Y (arcsecs)
-260
-240
-220
-200
-180
X (arcsecs)

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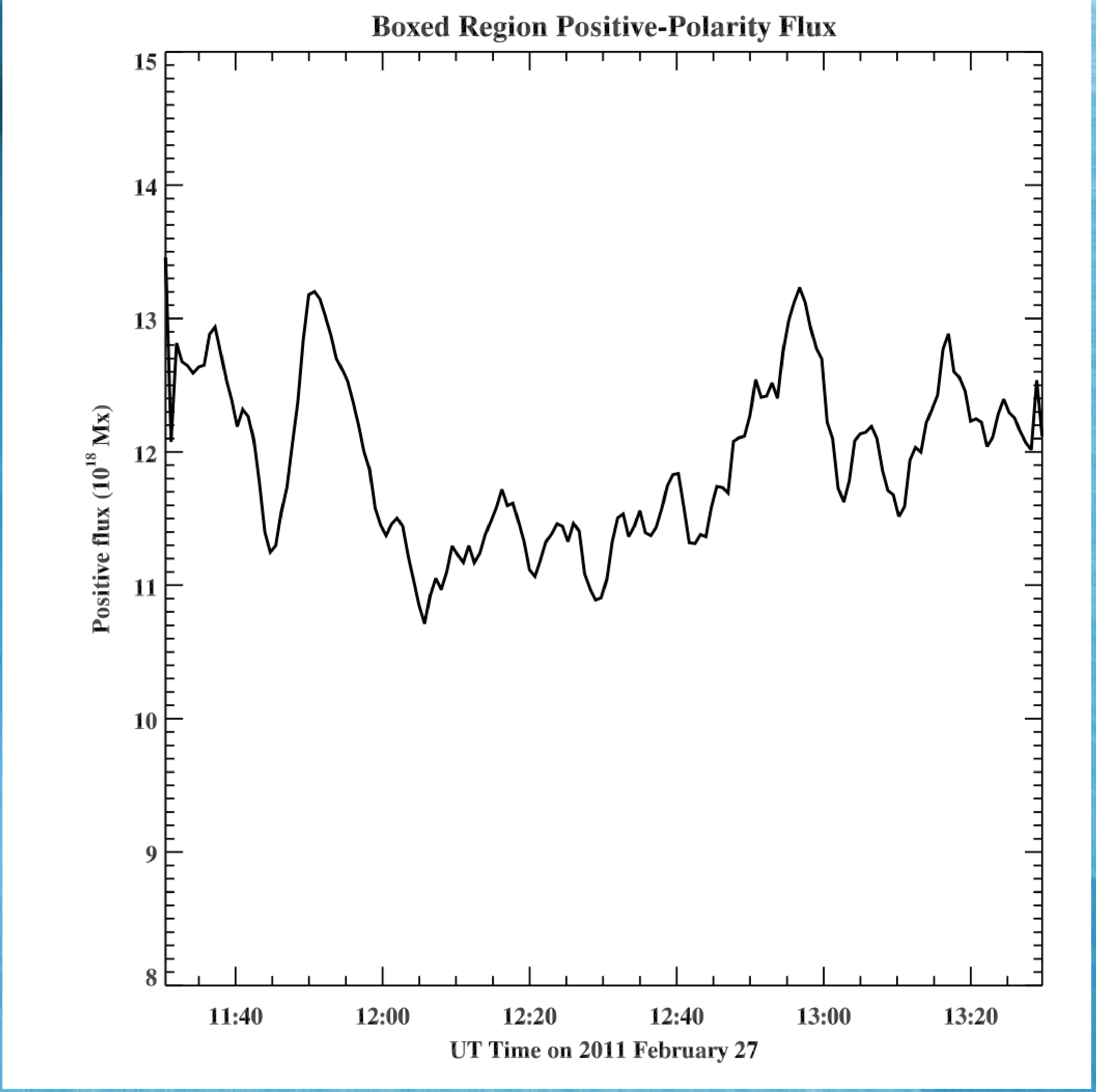
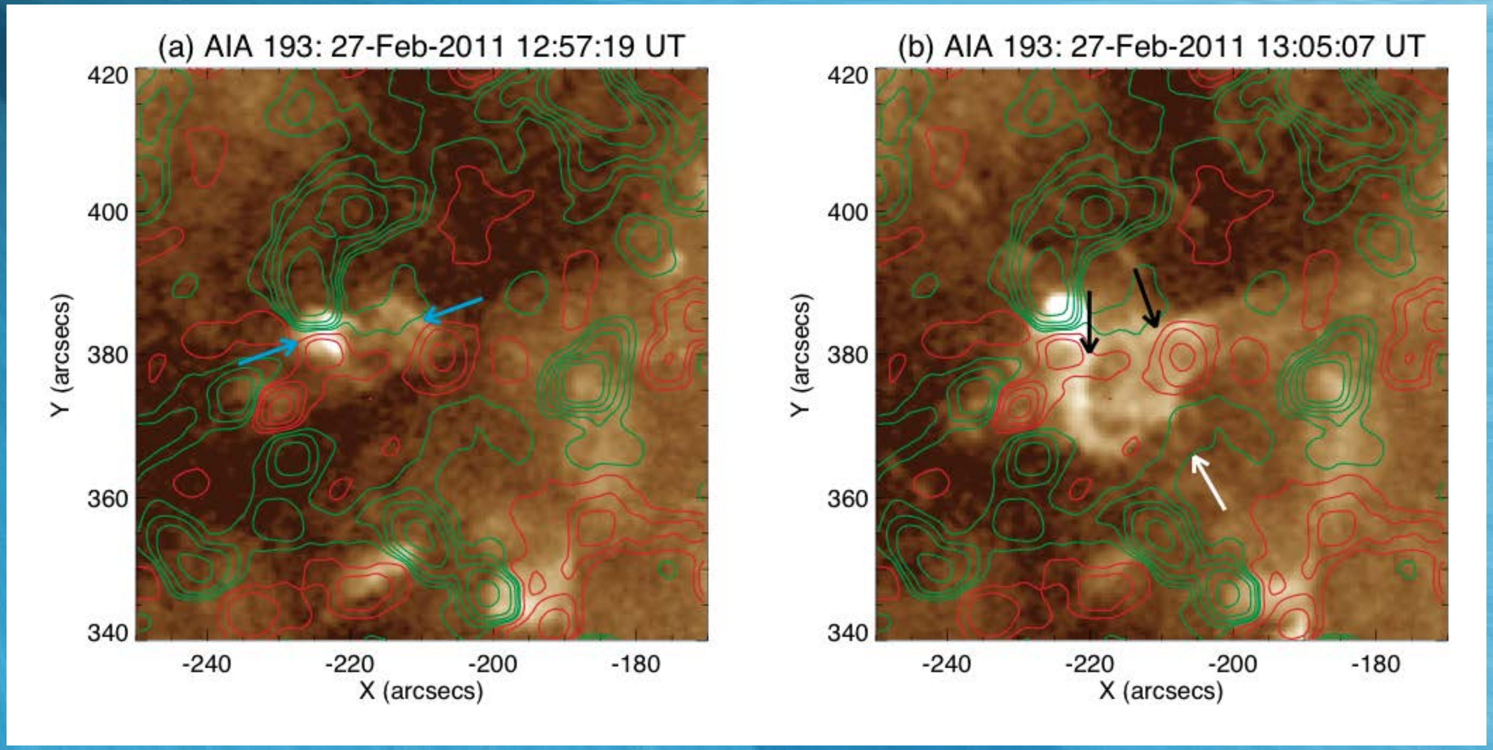
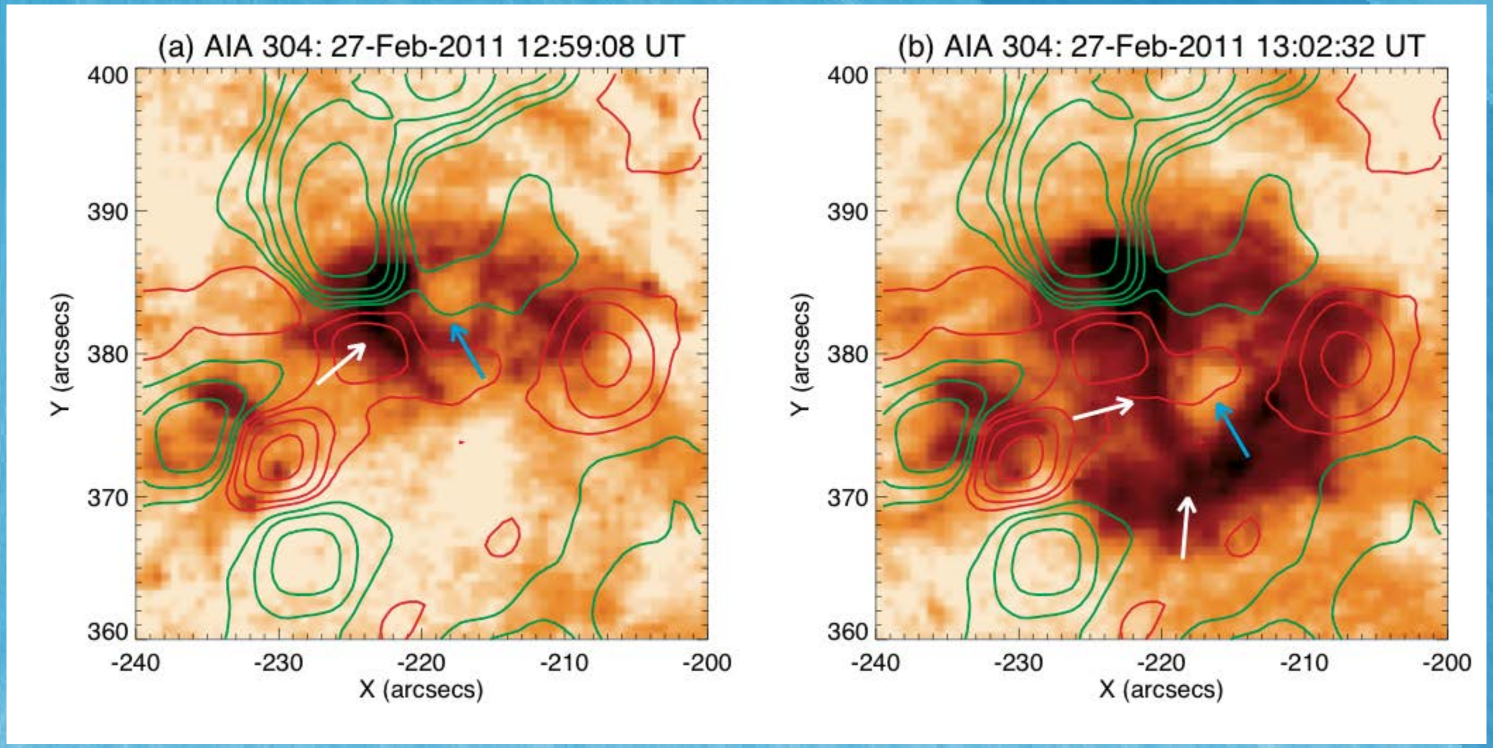


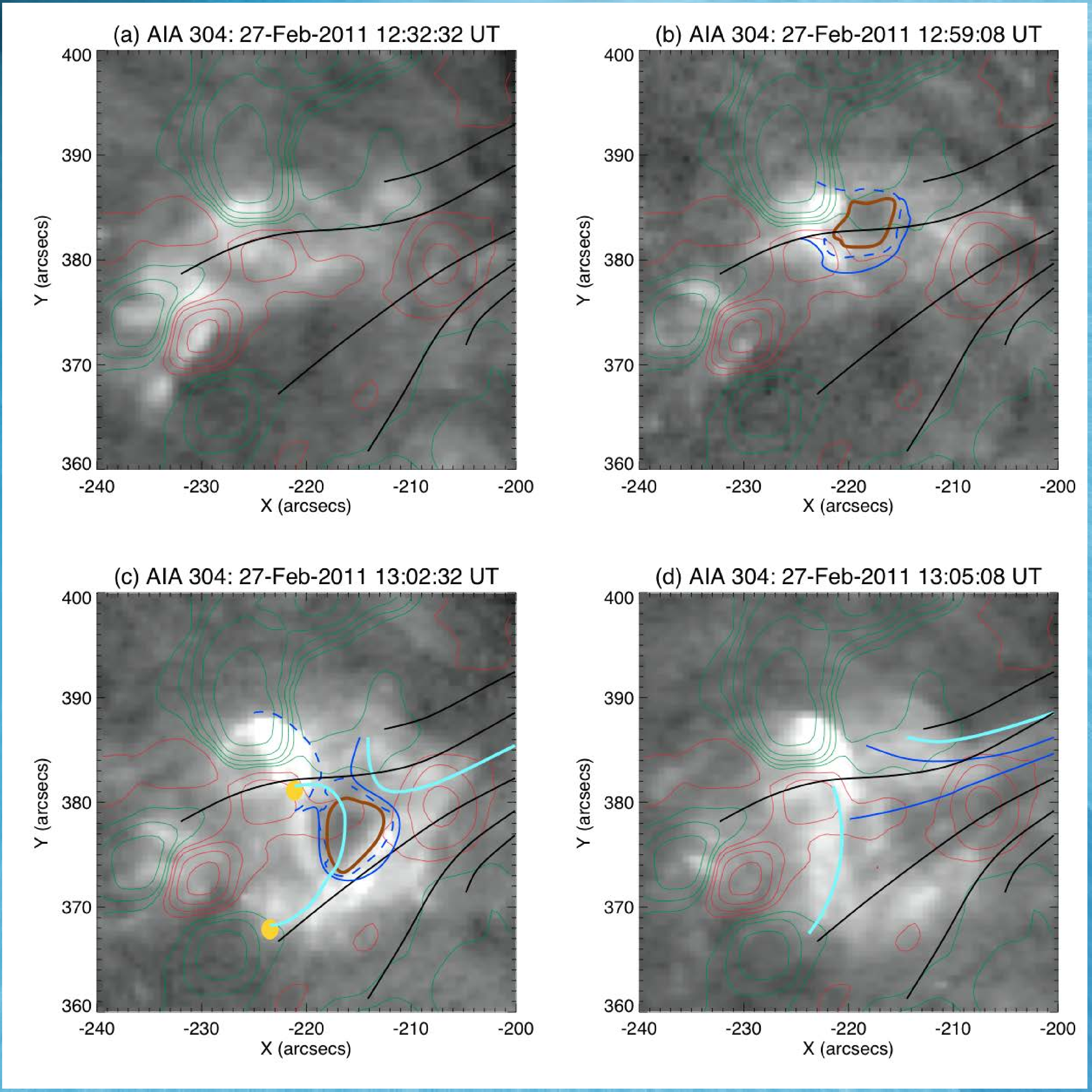

Variation <~20%; trend <~2x$10^{15}$ Mx/s
=> EF probably not driving the jet
(cf. Chandrashekhar et al. 2014)

# Also, no strong bipole under jet:




# Instead, probably have filament material from neutral line:



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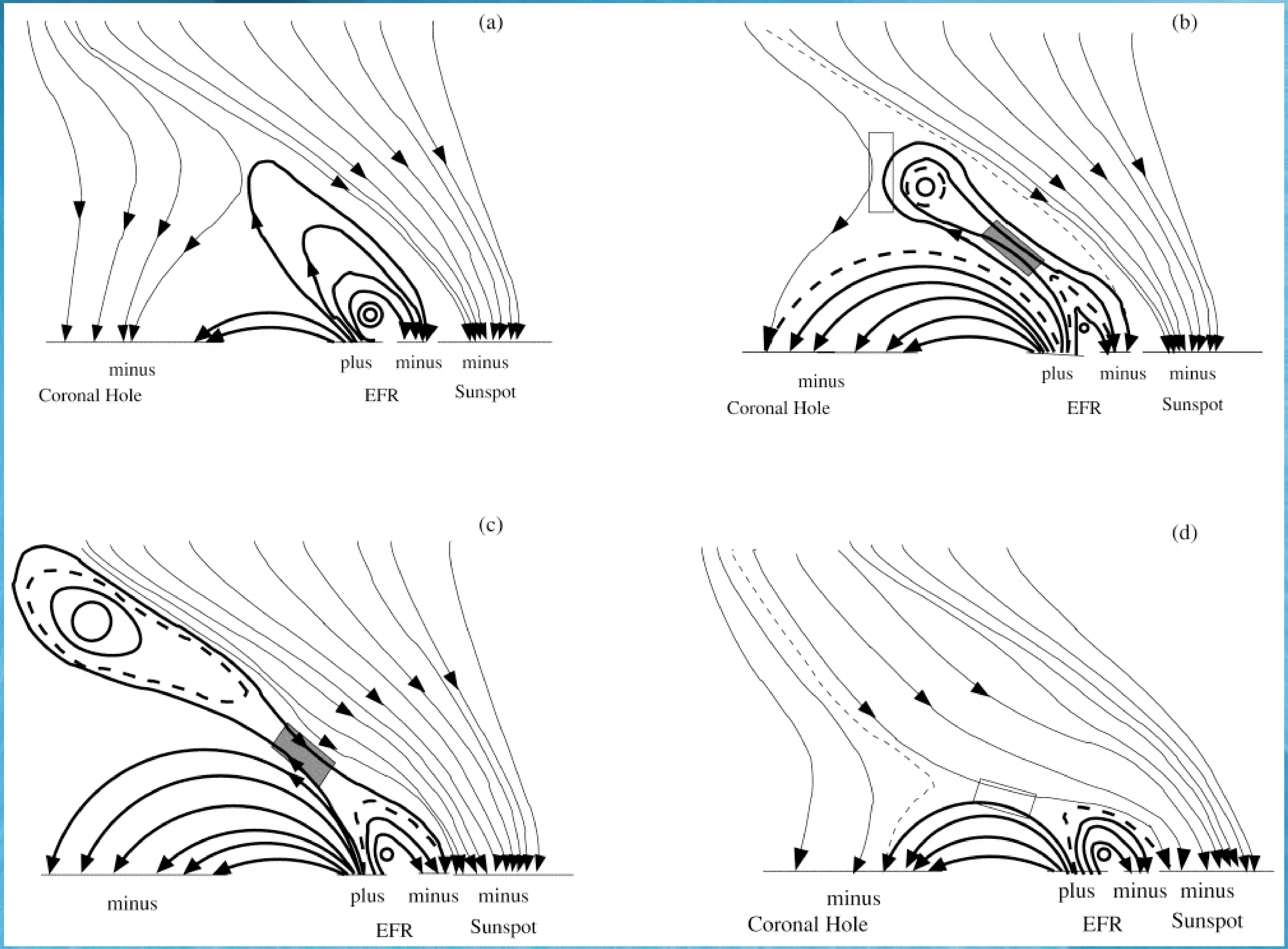


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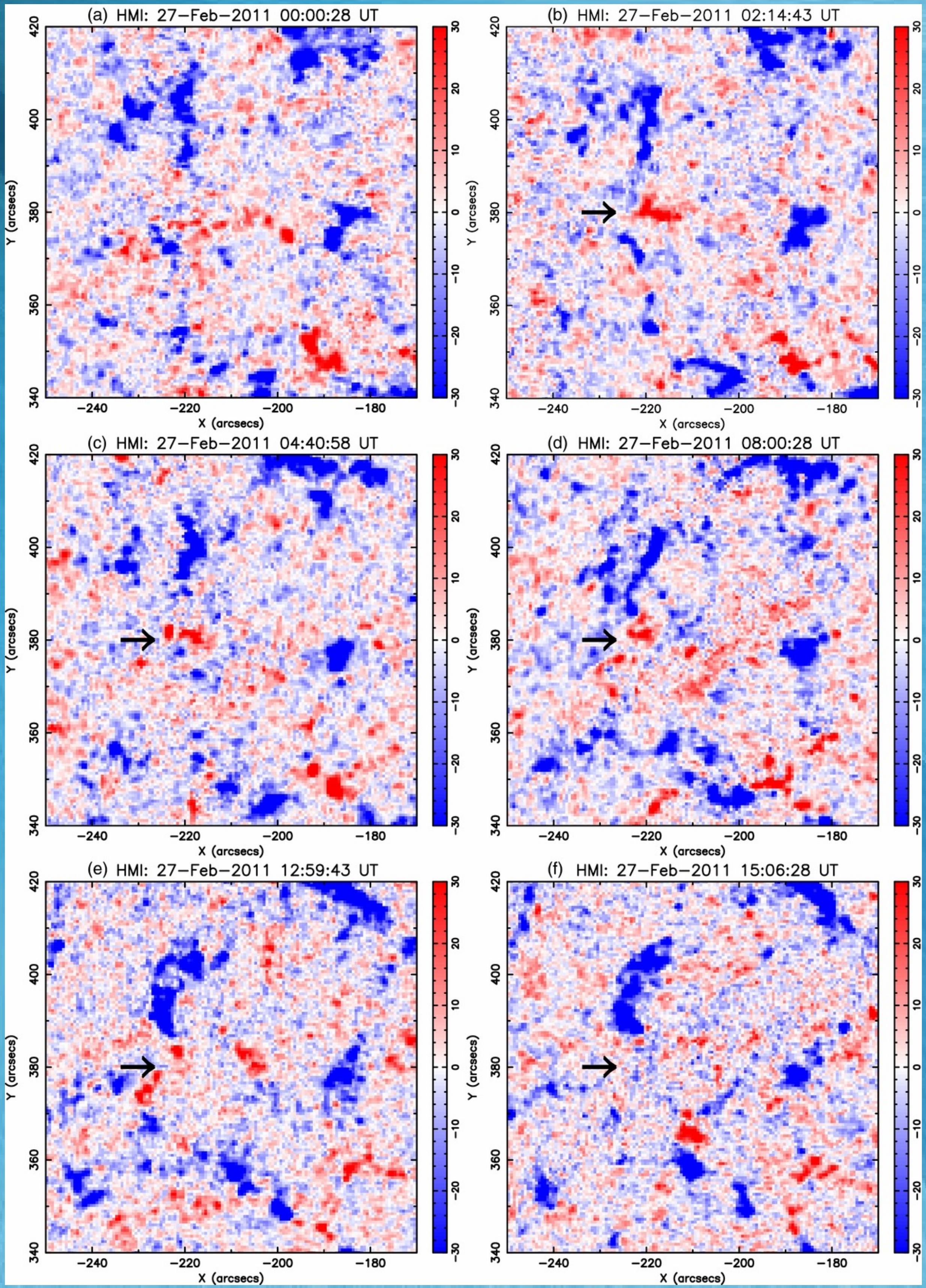


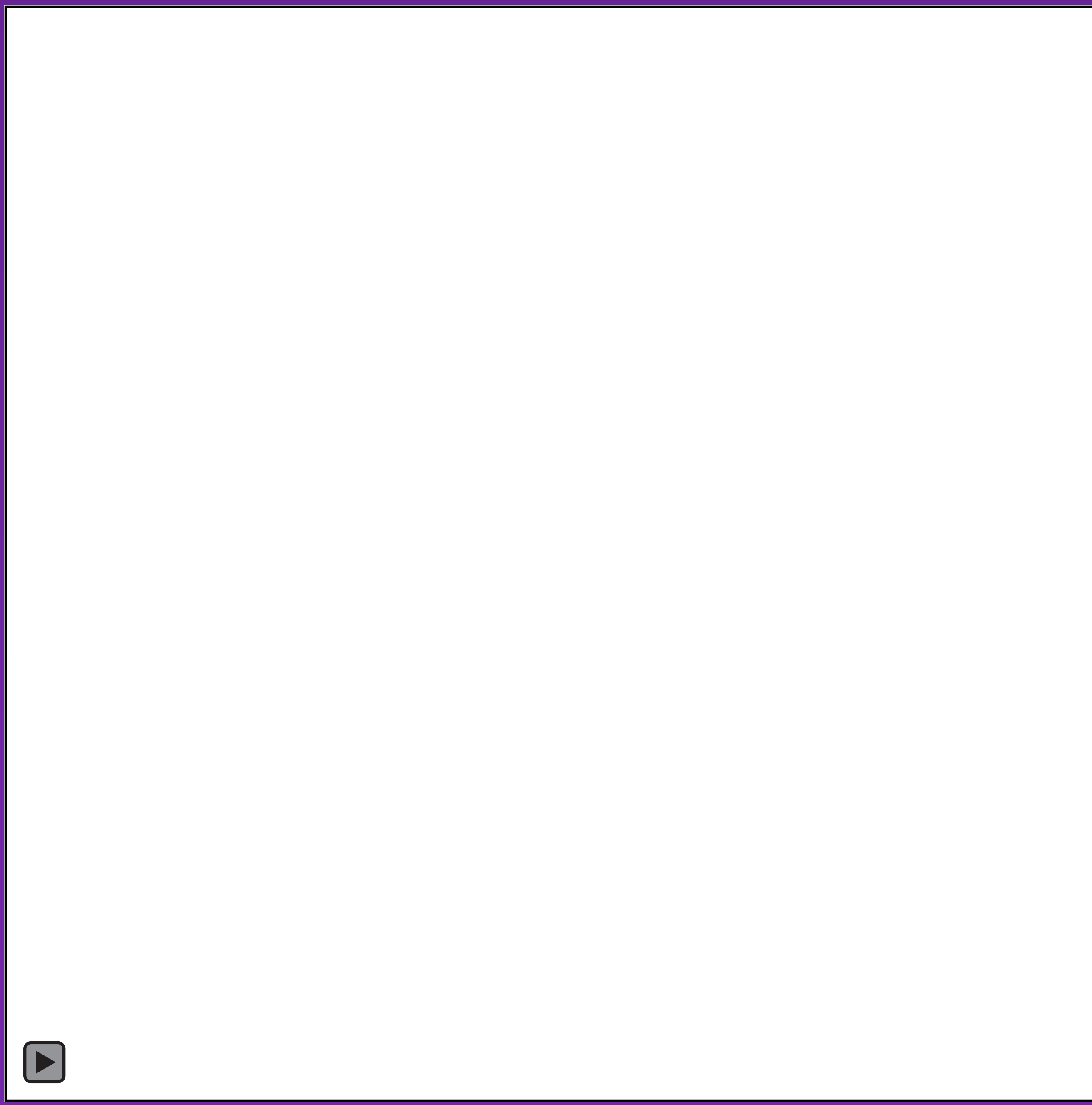

In this case, instead of emerging flux, have *canceling* flux!

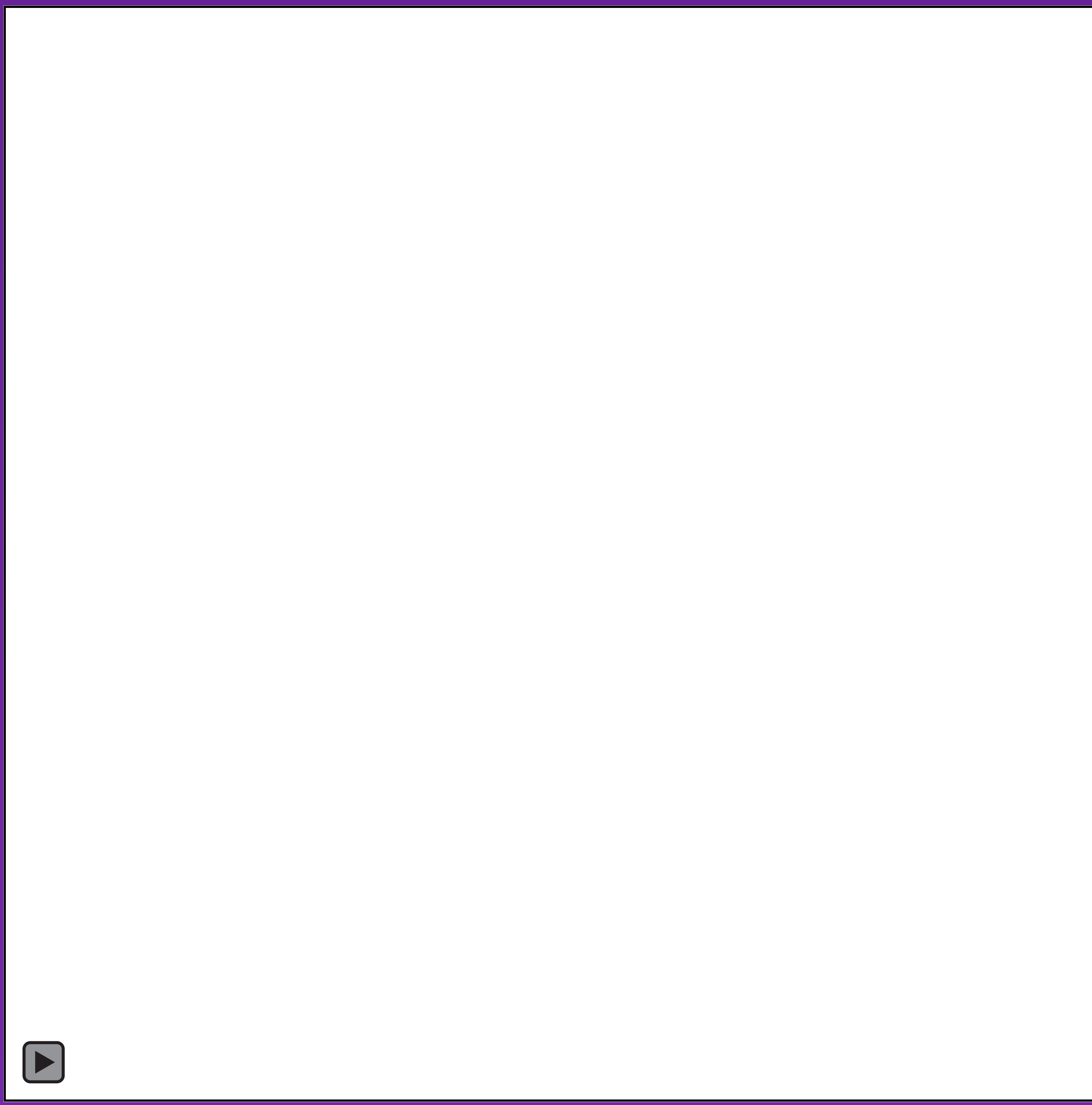
# With this background in mind, look at more events with AIA data

- Studied 20 Hinode/XRT X-ray jets polar coronal holes during SDO period.
- These jets were randomly selected during a previous investigation (Moore et al. 2013).
- For first several jets, examined all seven SDO/AIA EUV channels.
- For remaining jets, only examined AIA 304, 171, 193, and 211Å channels (~0.05, 0.6, 1.6, and 2.0 MK, respectively).

XRT

AIA 193





Event 12

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# XRT

# AIA 193

Event 18

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XRT

AIA 193

Event 3

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# “Normal” Filament Eruption (TRACE)

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XRT

AIA 304

Event 7

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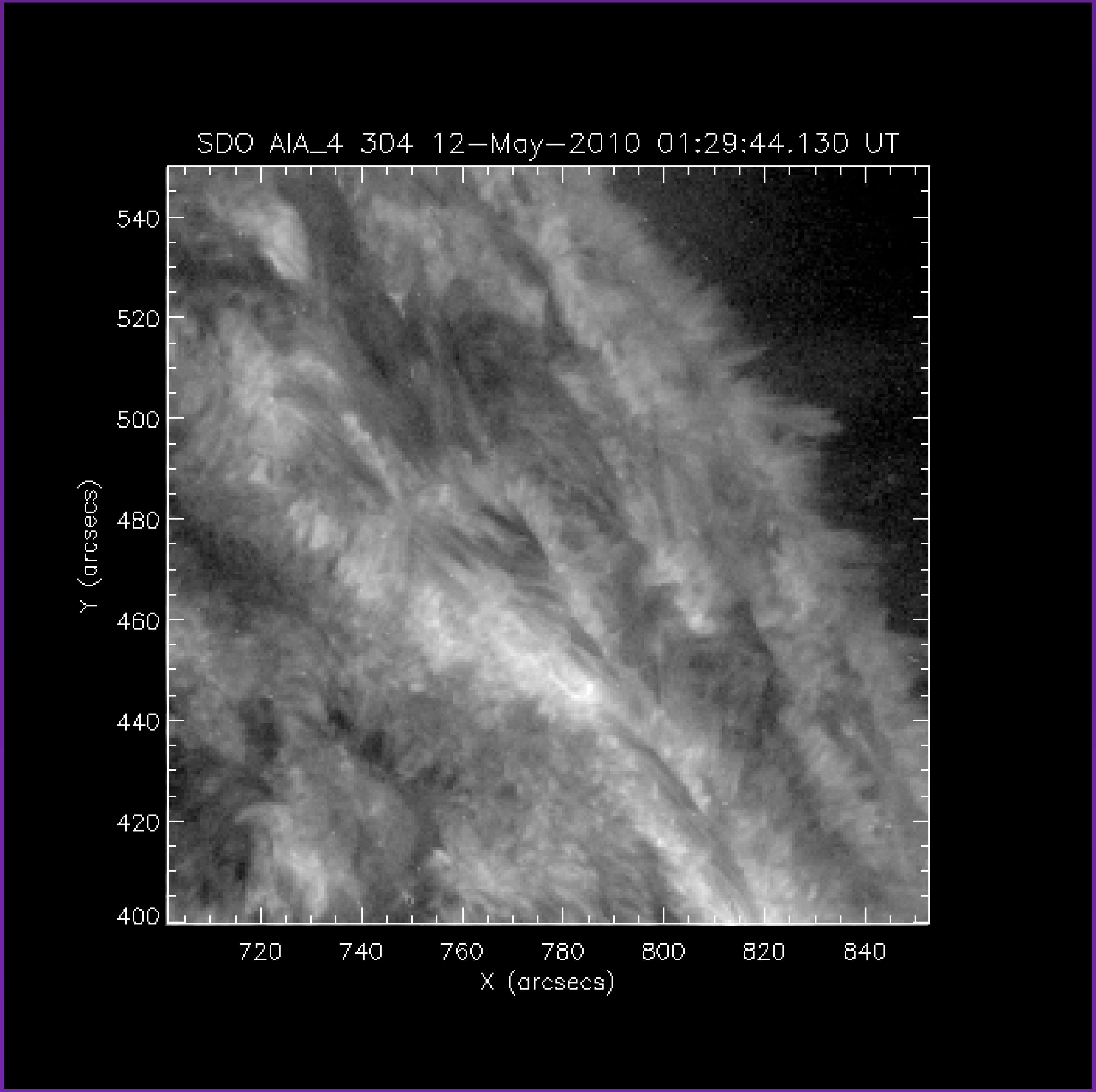
# “Normal” Filament Confined Eruption (AIA 304)






Sterling et al. (2011)

XRT

AIA 304

Event 7

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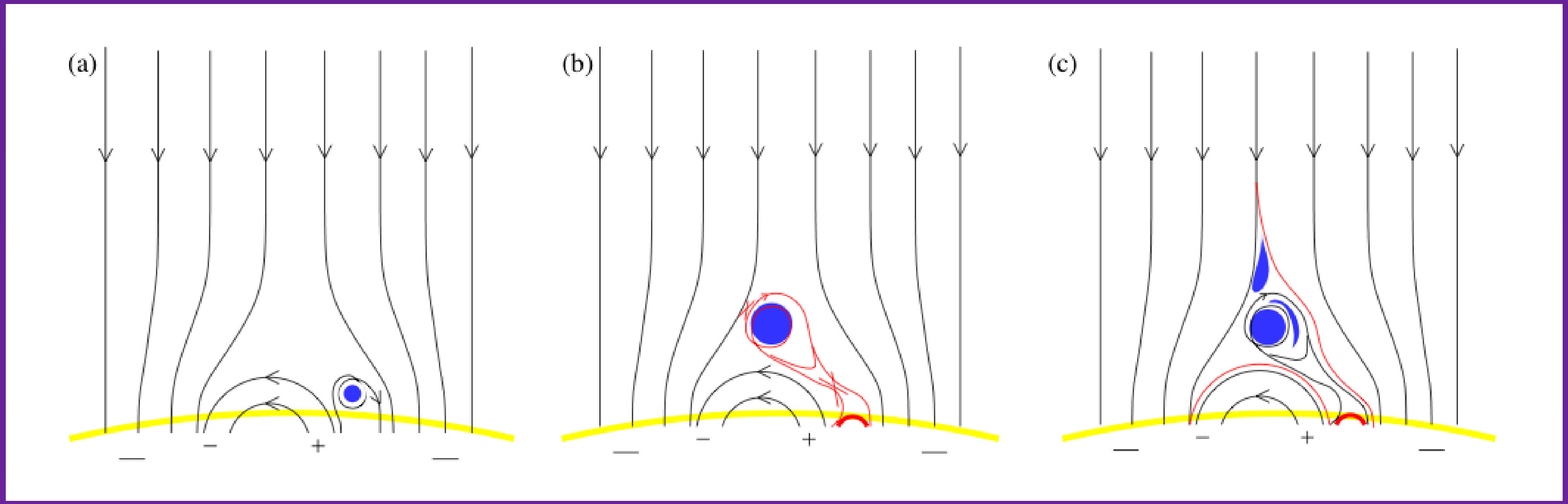
- All 20 events show filament material ejected from location that brightens.

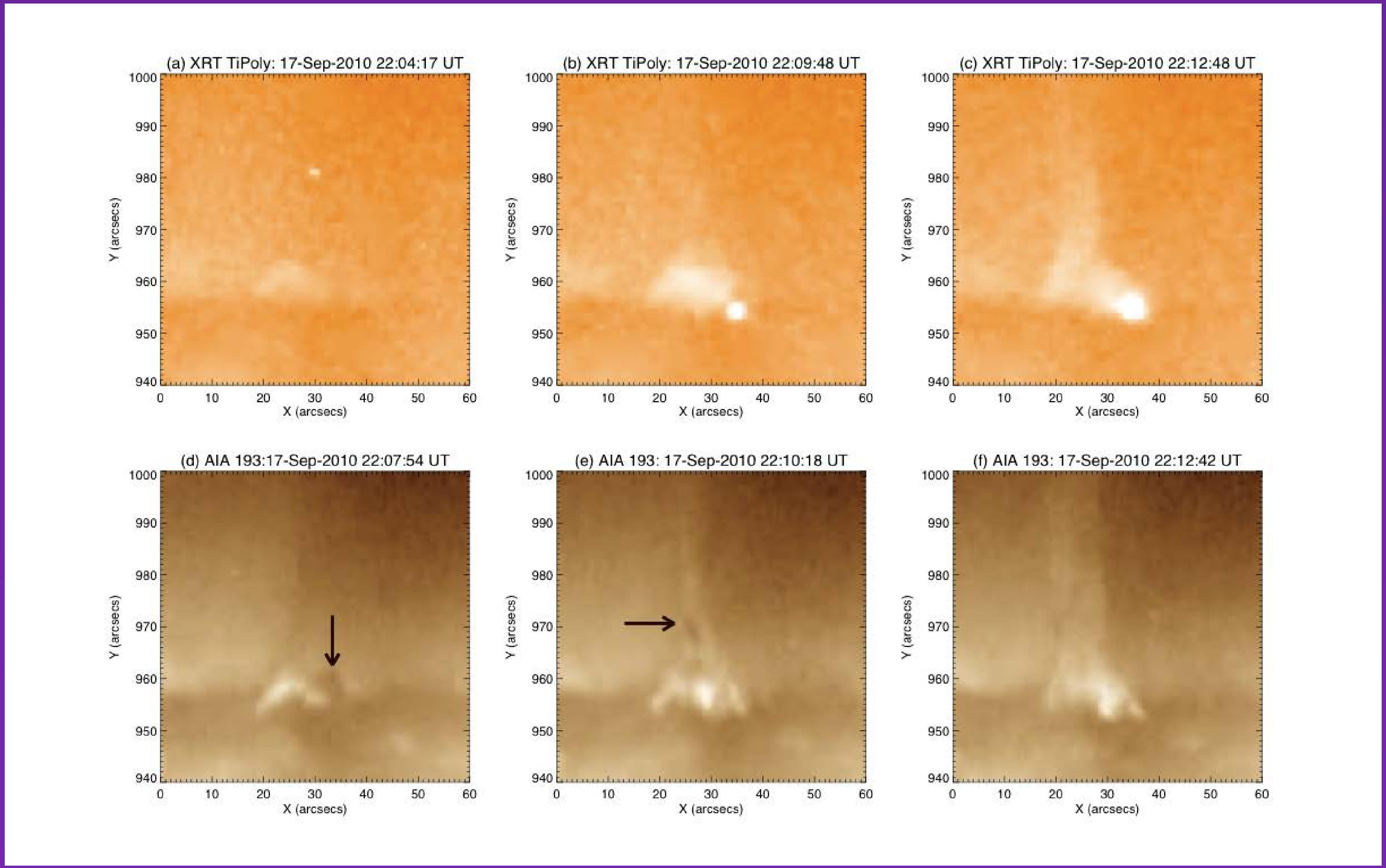
- "Standard" ejections (based on morphology) are sometimes fainter and harder to see than in "blowout" cases.  Seem to be confined or near-confined eruptions.

- Average (over 18 cases) miniature-filament properties:
    - Length ~$(8\pm3)\times10^3$ km.

    (cf. "normal" filaments: $3\times10^4$~$1.1\times10^5$ km; Bernasconi et  al. 2005)
    - Pre-ejection <velocity>= $31\pm15$ km/s.

# Revised View of X-Ray Jet Formation

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# How About On-Disk Jets?

- Not done in this study, but...
- Adams et al. (2014); above. Basic picture consistent with miniature filament eruption, with “flare” as the jet base brightening.
- Miniature filaments also seen by others, including Shen et al. (2012), Hong et al. (2014). (Also, Wang et al. 2000.)
- Other indications of eruptions making jets, e.g., Nisticò et al. (2009), Raouafi et al. (2010).

# On-Disk Jet

Shen et al. (2012)

# What Causes Miniature-Filament Eruptions?

- Did not look on-disk in this study, due to polar view.  But....

- Adams et al. (2014) found no emerging flux in the jet region. Filament erupted from location where flux canceled.
- Huang et al. (2012) and Young & Muglach (2014) found jet from location where flux canceled.
- Some others, e.g., Liu et al. (2011), Shen et al. (2012), and Hong et al. (2012) found jets from location of emerging flux+flux cancelation.

# Reconnection and Spire Drift in Coronal Jets


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# Main Points

- There are two kinds of X-ray jets in coronal holes: **standard** jets and **blowout** jets.

- In most jets of either kind, as the spire grows:
  - A bright point grows at the edge of the base of the jet, and
  - The spire drifts <u>away</u> from the bright point. [Cf. Savecheva et al. 2009.]

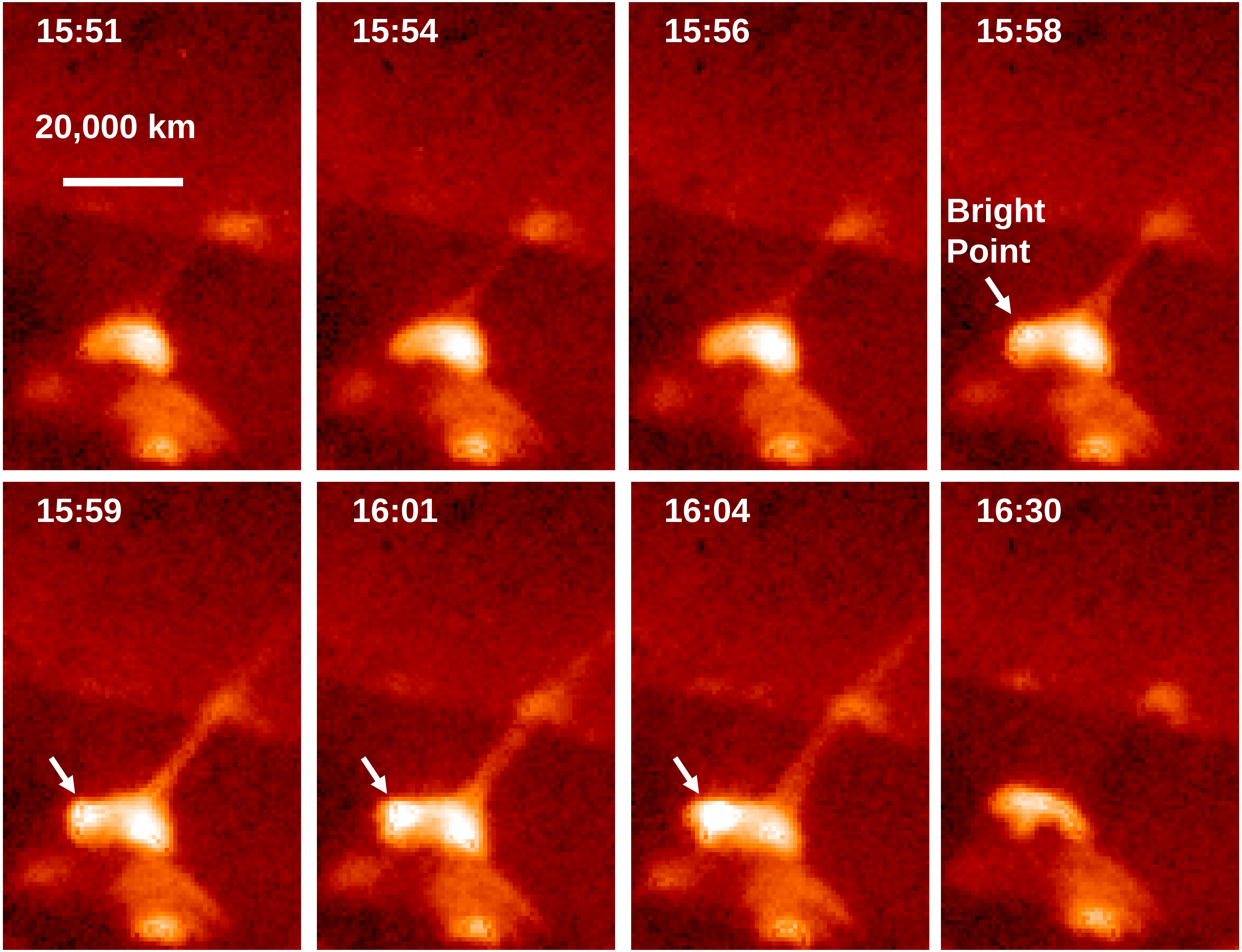
- The conventional emerging-flux model for jets implies: the spire should drift <u>toward</u> the bright point.

- Alphonse's minifilament-eruption model for jets implies: the spire should drift <u>away</u> from the bright point.

- ➡ The observed drift direction is explained by most coronal-hole X-ray jets being driven by a minifilament eruption instead of emerging flux.

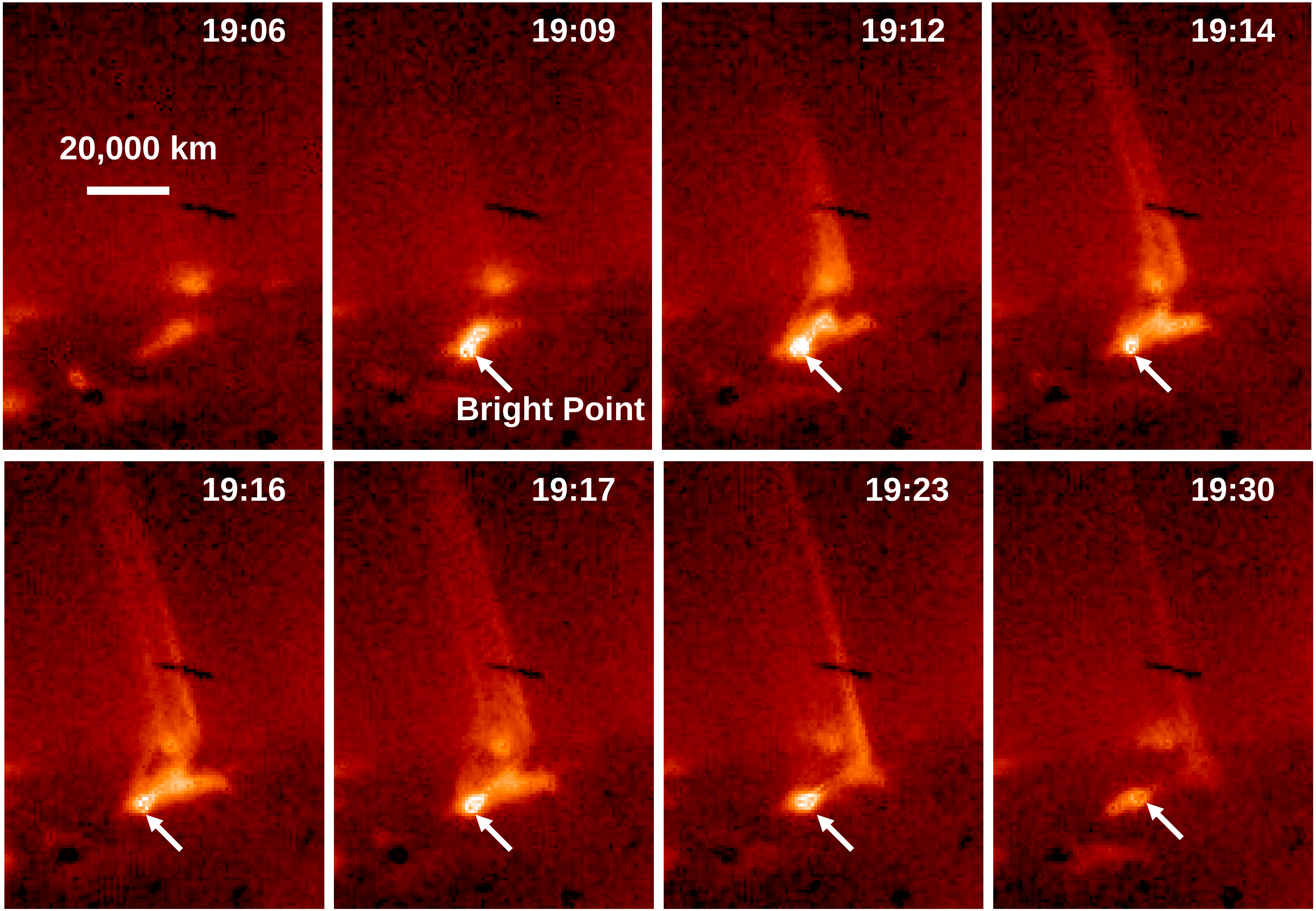
# Standard Jet

## Hinode/XRT Thin Al Poly, 2008 Oct 5

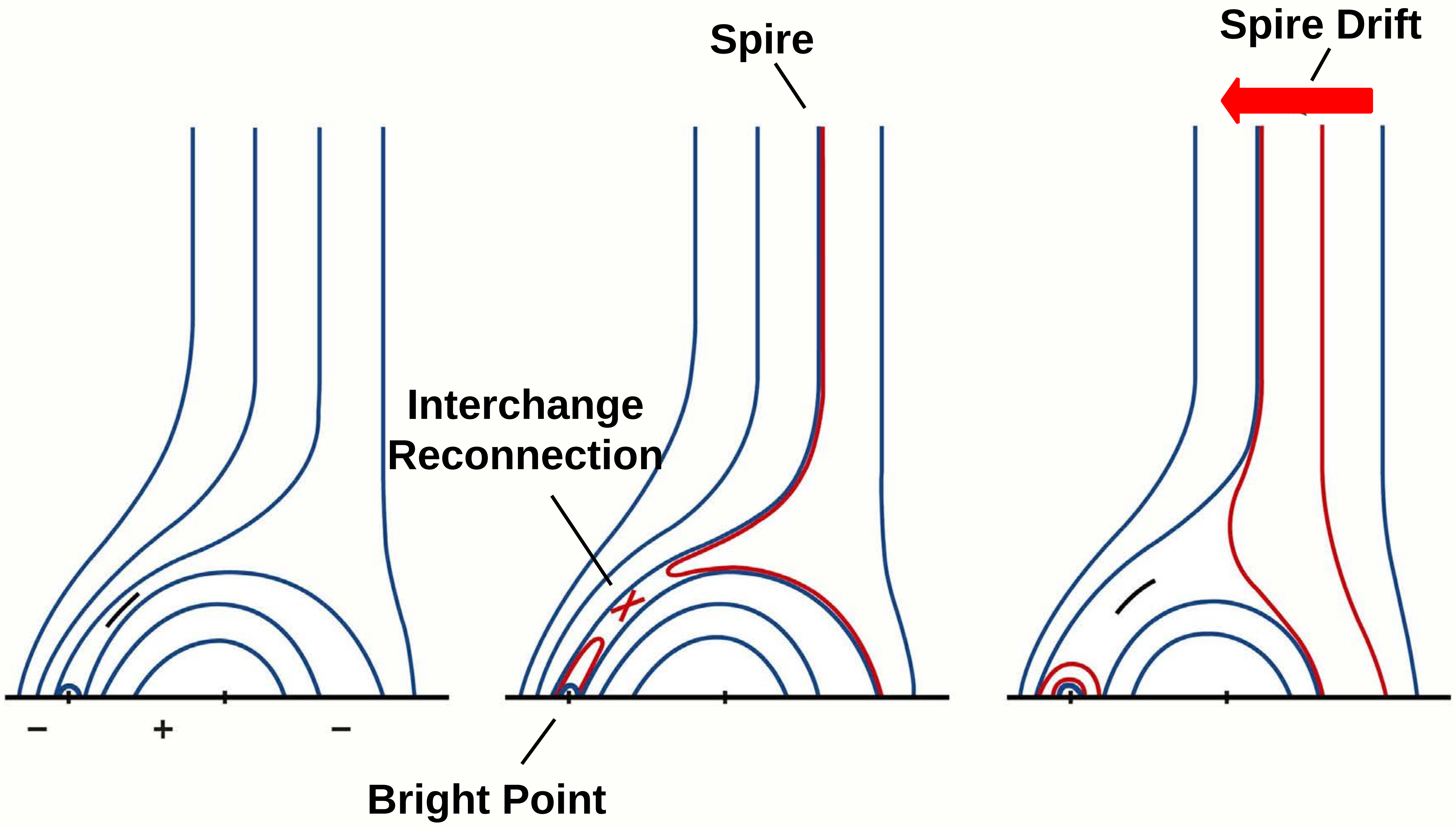


# Blowout Jet

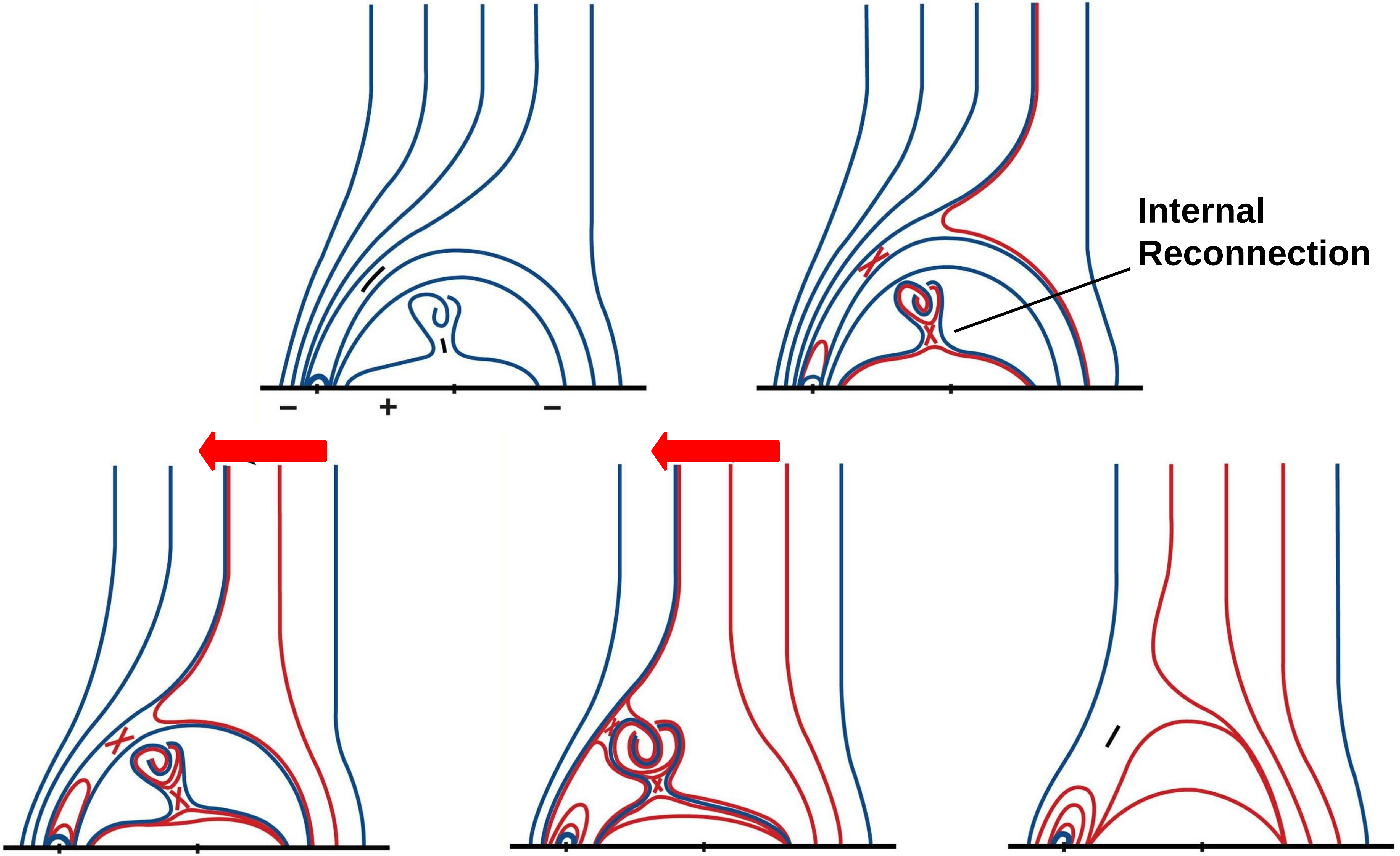
**Hinode/XRT Thin Al Poly, 2008 Sept 20**



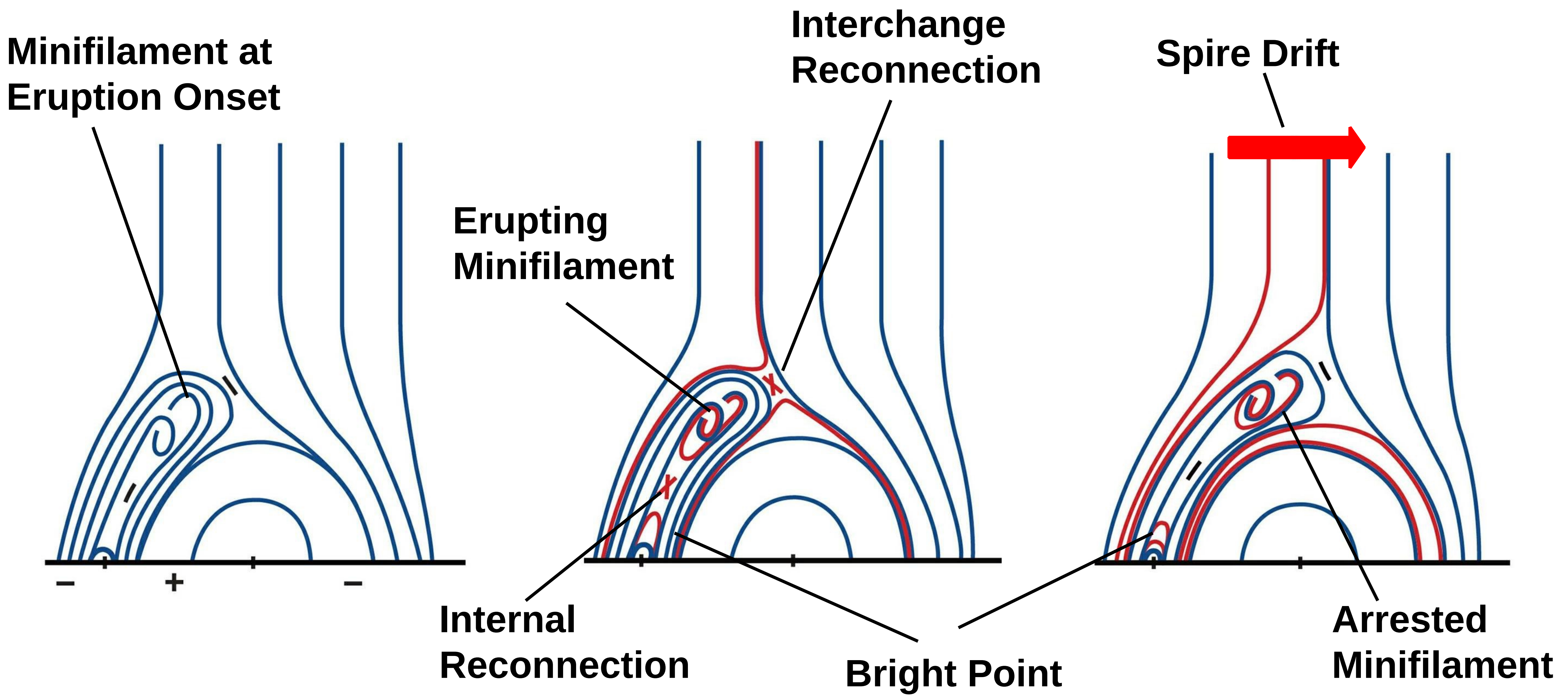
# Emerging-Flux Model for Standard Jets



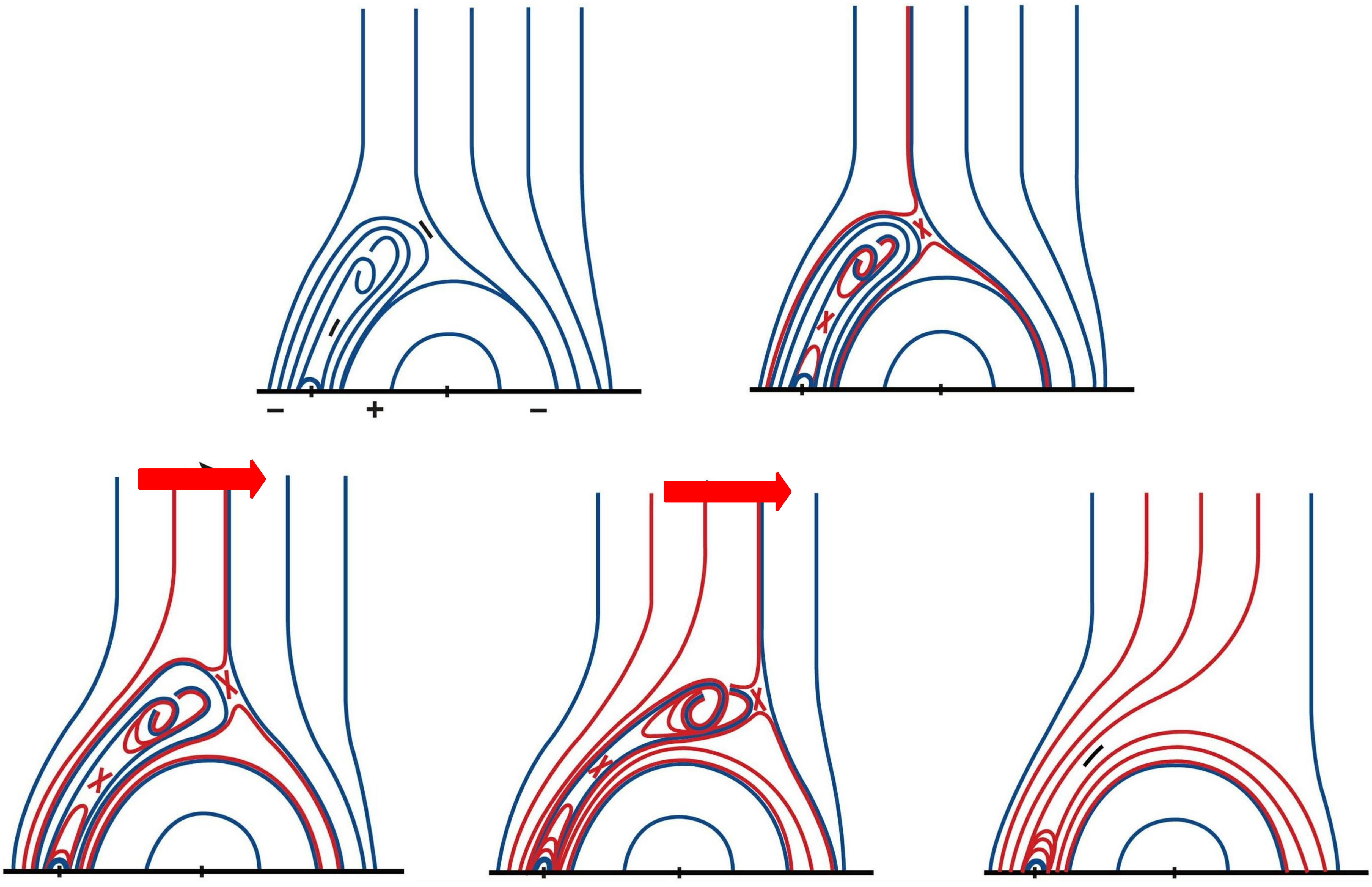
# Emerging-Flux Model for Blowout Jets



# Minifilament-Eruption Model for Standard Jets



# Minifilament-Eruption Model for Blowout Jets



# Conclusion

**For most X-ray jets in coronal holes,**
**the spire drift says:**

- **Alphonse's minifilament-eruption model is right.**
- **The conventional emerging-flux model is wrong.**

# Summary

- We observed 20 polar coronal hole X-ray jets with Hinode/XRT and SDO/AIA.
- Jets **due to eruptions of miniature filaments**: <length> ~$(8\pm3)\times10^3$ km; pre-ejection <velocity>= 31±15 km/s. Consistent with on-disk observations.
- Look like scaled-down larger-scale filament eruptions, where the jet-base hot-loop brightening corresponds to the flare.
- Spire drift with time is consistent with mini-filament idea, but not with emerging flux.
- Roughly speaking, blowout jets correspond to ejective eruptions, and standard jets correspond to confined eruptions.
- For some on-disk EUV jets, the miniature-filament eruptions result from flux cancelation, but cannot rule out other causes (flux emergences?).
- Finally: The jet base hot loop is due to internal reconnection, not external reconnection; reconnection at null might not be "sticky." (=>Astrophysical consequences?)